FLUIDIZATION IN CONICAL BED AND COMPUTATIONAL FLUID DYNAMICS (CFD) MODELING OF THE BED

A Project submitted to the

National Institute of Technology, Rourkela

In partial fulfilment of the requirements

Of

Bachelor of Technology (Chemical Engineering)

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CERTIFICATE

This is to certify that the thesis entitled "**Fluidization In Conical Bed And Computational Fluid Dynamics Modeling Of The Bed**", submitted by **Yogesh Chandra Moharana** and **Manoja Kumar Malik** to National Institute of Technology, Rourkela is a record of bonafide project work under my supervision and is worthy for the partial fulfilment of the degree of Bachelor of Technology (Chemical Engineering) of the Institute. The candidates have fulfilled all prescribed requirements and the thesis, which is based on their own work, has not been submitted elsewhere.

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ABSTRACT

Fluidization is the operation by which fine solids are transformed into a fluid like state through contact with a gas or liquid. This method of contacting has a number of unusual characteristics and fluidization engineering is concerned with efforts to take advantage of this behaviour and put it to good use.

Most of the gas solid fluidization behaviour studies have been performed in conventional or columnar fluidized bed, but industrial fluidized beds are frequently manufactured with a conical or tapered section at the bottom. The use of conical fluidized beds is beginning to receive much attention for biochemical reactions and biological treatment of waste water, also been used successfully in chemical reactions, crystallizations and in other areas.

In this paper, the bed hydrodynamics especially pressure drop, and minimum fluidization velocity in terms of superficial velocity at the bottom of the bed, and flow regimes, such as fixed bed, partially fluidized bed and fluidized bed, is to be studied successively with the increase of superficial gas velocity in a conical bed with different bed height, particle size both experimentally and by computational fluid dynamics modelling of the bed using Ansys 13.0. The results have been compared with the calculated data from the experimental work and have been found to agree well.

Key words: Fluidization, Conical fluidization, CFD

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NOMENCLATURE

$$A = 150 \frac{(1-\varepsilon_{mf})^2}{\varepsilon_{mf}^{\ 3}} \frac{\mu_f}{(\phi_s d_p)^2}$$

$$B = 1.75 \frac{1-\varepsilon_{mf}}{\varepsilon_{mf}^{\ 3}} \frac{\rho_f}{\phi_s d_p}$$

D_i	diameter of the bed bottom (m)
D_t	diameter of spouted bed (m)
D_p	particle diameter (m)
F	drag force (N)
G	weight of powder (kg)
g	acceleration due to gravity (ms^{-2})
H_m	stagnant bed height (m)
h	height (m)
ΔP_{max}	maximum total pressure drop (Pa)
ΔP_{maxl}	maximum pressure drop in fixed bed zone (Pa)
dP/dh	pressure gradient (Pam^{-1})
ΔP_t	total pressure drop (Pa)
ΔP_{sp}	spouting pressure drop (Pa)
$(Reo)_{ms}$	Reynolds number at u_{ms}
r	radius of cross-section (m)
r_0	inlet radius (m)
r_1	radius of the bed at the top (m)
u_g	gas velocity (ms^{-1})
u_{g0}	superficial gas velocity (ms^{-1})
u_{mf}	minimum fluidization velocity (ms^{-1})
u_{ms}	minimum spouting velocity (ms^{-1})
u_s	solid velocity (ms^{-1})

CHAPTER 1

INTRODUCTION

Fluidization [1, 2] is the operation by which fine solids are transformed into a fluid like state through contact with a gas or solid. This method of contacting has a number of unusual characteristics and fluidization engineering is concerned with efforts to take advantage of this behaviour and put it in good use. When a liquid or gas is passed at very low velocity up through a bed of solid particles, the particles do not move, and the pressure drop is given by the Ergun’s equation [3]. If the fluid velocity is steadily increased, the pressure drop and the drag on individual particles increase, and eventually the particles start to move and become suspended in the fluid .The terms fluidization and fluidized bed are used to describe the condition of fully suspended particles, since the suspension behaves as a dense fluid. The ease with which particles fluidize and the range of operating conditions which sustain fluidization vary greatly among gas solid systems. Whether the solids are free flowing or not, whether they are liable to agglomerate, static charges, vessel geometry, gas inlet arrangement, and other factors affect the fluidization characteristics of a system [4].

In spite of many advantages claimed for the fluidization phenomenon, the efficiency and quality of large scale and deep gas solid continuous fluidized beds are seriously affected by bubbling and slugging behaviour, when gas velocities are higher than the minimum fluidization velocity. The solution to the above problem of gas-solid fluidization is the use of a conical vessel instead of a conventional cylindrical one. Conical fluidized bed is very much useful for the fluidization of wide distribution of particles, since the cross sectional area is enlarged along the bed height from the bottom to the top, therefore the velocity of the fluidizing medium is relatively high at the bottom, ensuring fluidization of the large particles and relatively low at the top, preventing entrainment of the small particles. Since the velocity of fluidizing medium at the bottom is fairly high, this gives rise to low particle concentration, thus resulting in low reaction rate and reduced rate of heat release. Therefore the generation of high temperature zone near the distributor can be prevented.

1.1 Application of Conical Bed Fluidization

Due to the existence of a gas velocity gradient along the height of a conical bed, it has some favourable special hydrodynamic characteristics. The conical bed has been widely applied in many industrial processes such as

[1] Biological treatment of waste-water,

[2] Immobilization biofilm reaction,

[3] Incineration of waste-materials,

[4] Coating of nuclear fuel particles,

[5] Crystallization, roasting of sulphide ores,

[6] Coal gasification and liquefaction,

[7] Catalytic polymerization,

[8] Fluidized contactor for sawdust and mixtures of wood residues and

[9] Fluidization of cohesive powder.

1.2 Advantages of Conical Bed Fluidization

- ✓ Promotes solid mixing
- ✓ Prevents stagnant solids build up
- ✓ Minimizes solids segregation
- ✓ Facilitates the easy discharge of solids

1.3 Possible Disadvantages

- ✓ Fluid like behaviour of the fine solid particles within the conical bed results in abrasion leading to the erosion of pipes and vessels connected to it
- ✓ Requires careful design to ensure good gas distribution
- ✓ Requires high pressure drop for good gas distribution

CHAPTER 2
LITERATURE REVIEW

2.1 The phenomenon of fluidization

On passing fluid (gas or solid) upward through a bed of fine particles, at a low flow rate fluid merely percolates through the void spaces between stationary particles. This is a fixed bed. With an increase in flow rate, particles move apart and a few are seen to vibrate and move about in restricted regions. This is expanded bed. At a still higher velocity, the pressure drop through the bed increases [5]. At a certain velocity the pressure drop through the bed reaches the maximum and a point is reached when the particles are all just suspended in the upward flowing gas or liquid. At this moment, the particles at the bottom of the bed begin to fluidize, thereafter the condition of fluidization will extend from the bottom to the top and the pressure drop will decline fairly sharply [6, 7].

Evidently, fluidization is initiated when the force exerted between a particle and fluidizing medium counterbalances the effective weight of the particle, the vertical component of the compressive force between the adjacent particles disappears, and the pressure drop through any section of the bed about equals the weight of fluid and particles in that section. The bed is considered to be just fluidized and referred to as an incipiently fluidized bed or a bed at minimum fluidization [9, 10]. Under the assumption that friction is negligible between the particles and the bed walls also it is assumed that the lateral velocity of fluid is relatively small and can be neglected and the vertical velocity of the fluid is uniformly distributed on the cross sectional area.

Gas-solid systems generally behave in quite different manner. With an increase in flow rate beyond minimum fluidization, large instabilities with bubbling and channelling of gas are observed. At higher flow rates agitation becomes more violent and the movement of solids becomes vigorous. In addition, the bed does not expand much beyond its volume at minimum fluidization. Such a bed is called an aggregative fluidized bed [11, 12], a heterogeneous fluidized bed, a bubbling fluidized bed, or simply a gas fluidized bed.

2.2 Variables affecting the quality of fluidization

Some of the variables affecting the quality of fluidization [15, 16] are:

- Fluid inlet: It must be designed in such a way that the fluid entering the bed is well distributed.
- Fluid flow rate: It should be high enough to keep the solids in suspension but it should not be so high that the fluid channelling occurs [17, 18, 19].
- Bed height: With other variables remaining constant, the greater the bed height, the more difficult it is to obtain good fluidization.
- Particle size: It is easier to maintain fluidization quality with particles having a wide range than with particles of uniform size.
- Gas, Liquid and solid densities: The closer the relative densities of the gas, liquid and the solid, the easier are to maintain smooth fluidization.
- Bed internals: In commercial fluidizers internals are provided to perform the following functions.
  - ✓ To prevent the growth of bubble sizes
  - ✓ To prevent lateral movement of fluid and solids
  - ✓ To prevent slug formation
  - ✓ To prevent elutriation of fine particles

2.3 Flow regimes of conical bed

A typical diagram of the hydrodynamic characteristics of the conical bed [6] is shown I fig. With the increase of superficial gas velocity, U_{go}, the total pressure drop, ΔP, varies along the line A-B-C-D.

In the different stages, the hydrodynamic characteristics of fluidization of the conical bed are as follows:

A-B stage: because U_{go} is relatively low, the stagnant height of the particle bed remains unchanged as at the beginning. The total pressure drop, ΔP, increases up to the maximum point, ΔP_{max} , i.e. point A as shown in fig and the flow regime is termed as the fixed bed

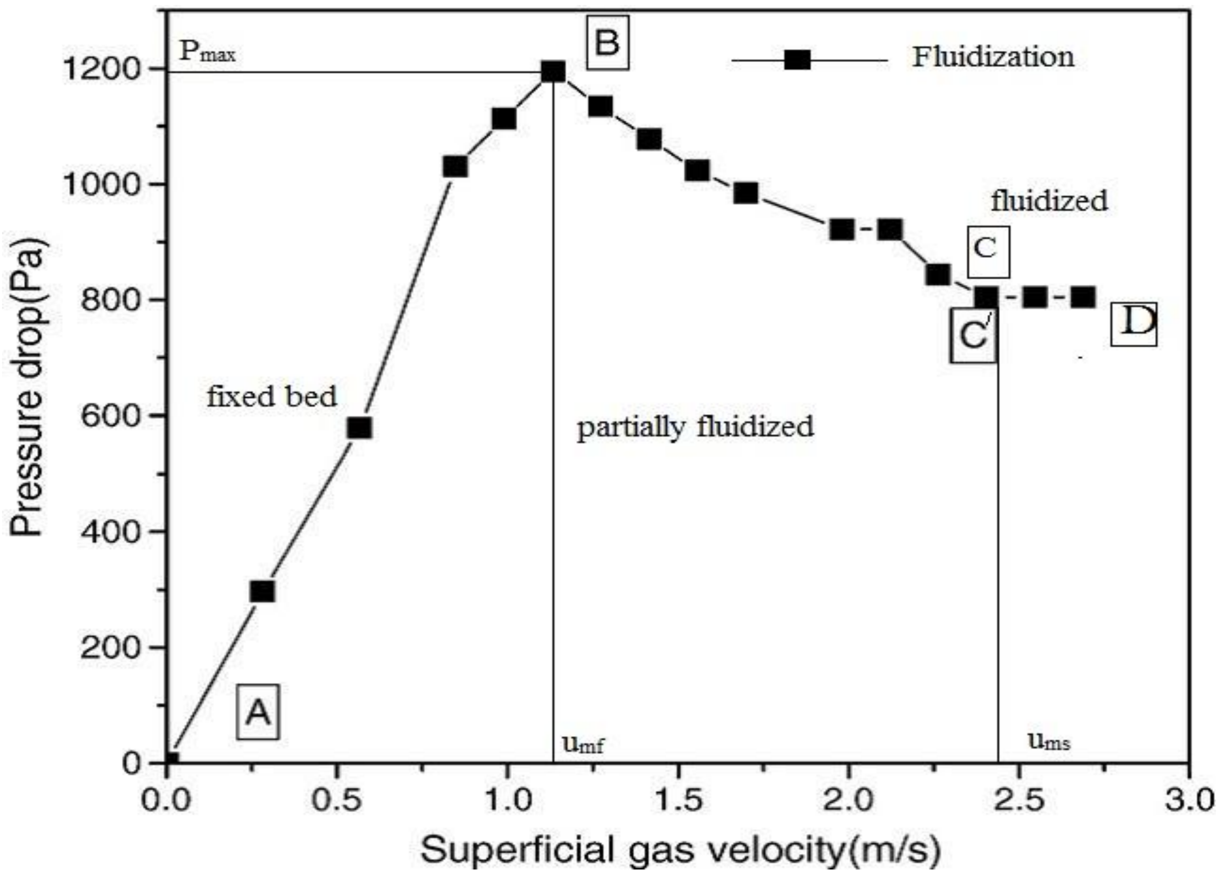


Fig 1. Hydrodynamics characteristics of the bed (Pressure drop variation with superficial gas velocity)

regime. The superficial gas velocity, to which point A corresponds, is called the minimum fluidized velocity, U_{mf}.

B-C stage: When U_{go} is higher than U_{mf} as shown in fig ΔP decreases with the increase of U_{go}, and it is observed that the stagnant height of the conical bed does not change. The flow regime is named as partially fluidized bed. When U_{go} reaches Ums, the characteristics of total pressure drop are different from those in the above two stages.

C-D stage: if U_{go} is greater than Ums, ΔP stays nearly constant as shown in fig, the bed is said to be in fully fluidized condition. The characteristics of fluidization of the gas-solid conical bed are different from that of liquid-solid ones. Depending on the cone angle, the flow regime is called as a slugging or spouting fluidization regime [20, 21].

2.4 Structure of Conical Bed

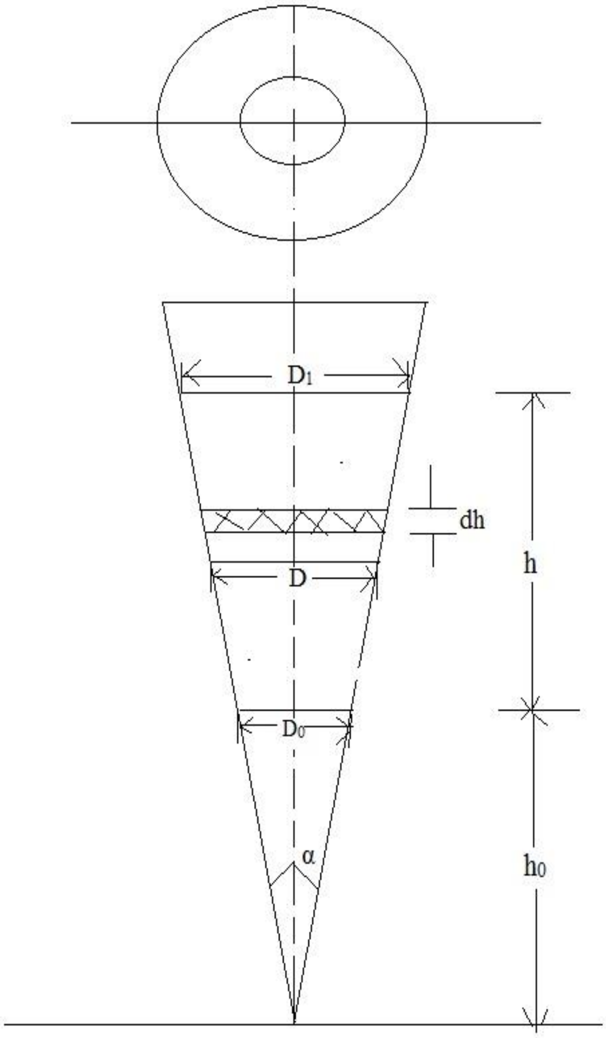


Fig 2 Structure of conical bed

2.5 Need for CFD

Computational fluid dynamics is a totally new field which needs to be explored very well. Over the years there have been a lot of computational works but in comparison to the large experimental data available, more works in the field of CFD is required. CFD predictions can be verified with the experimental data and results and can be checked whether they hold good or not. With the experimental work being very tedious, CFD helps in predicting the fluid flow, behavior of the fluidized bed and various hydrodynamic characteristics. CFD actually helps in modeling the prototype of a real world process and through CFD predictions one can apply those parameters to achieve the desired results. Thus the complex hydrodynamics of fluidization could be understood using CFD.

Objective of the work:

The aim of the present work could be summarized as follows:

- ✓ Study of complex hydrodynamics of gas-solid tapered fluidized bed.
- ✓ Study of pressure drop across the bed.
- ✓ Study of bed height variation with gas velocity and pressure drop.
- ✓ Computational fluid dynamics analysis of the bed.

2.6 Equation involved

2.6.1 Equation for total pressure drop in a fixed bed

The gas velocity distribution [7] in the cross section of the conical bed is uniform. Therefore, in the fixed bed regime, Ergun's equation is adopted for calculating the pressure drop

$$-\frac{dp}{dh} = \frac{150(1-\varepsilon)^2 \mu_g (u_g - u_s)}{\varepsilon^3 (\phi_s d_p)^2} + \frac{1.75(1-\varepsilon)\rho_g (u_g - u_s)^2}{\varepsilon^3 (\phi_s d_p)} \tag{1}$$

Where u_s=0 u_s= solid velocity

u_g= gas velocity

If the void age remains uniform with bed height the gas velocity μ_g in the conical bed is given as

$$u_g = u_{go} \frac{(r_o + h\tan\left(\frac{\alpha}{2}\right))^2}{{r_o}^2} \tag{2}$$

By substituting equation (2) in equation (1) Ergun's equation becomes

$$-\frac{dp}{dh} = \frac{150(1-\varepsilon)^2 \mu_g u_g}{\varepsilon^3 (\phi_s d_p)^2 \left[1+\frac{\tan\left(\frac{\alpha}{2}\right)h}{r_o}\right]^2} + \frac{1.75(1-\varepsilon)\rho_g u_{go}}{\varepsilon^3 (\phi_s d_p) \left[1+\frac{\tan\left(\frac{\alpha}{2}\right)h}{r_o}\right] 4} \tag{3}$$

Where u_{go} =superficial gas velocity, α=angle of cone

$$-\Delta p = \frac{150(1-\varepsilon)^2 \mu_g u_{go} r_o \left[1-\frac{1}{\left(1+\frac{\tan\left(\frac{\alpha}{2}\right)h}{r_o}\right)}\right]}{\varepsilon^3 (\phi_s d_p)^2 \tan\left(\frac{\alpha}{2}\right)} + 1.75\ (1-\varepsilon)\rho_g r_o u_{go}^2 [1 - \frac{1}{\left(1+\tan\left(\frac{\alpha}{2}\right)\right)h} / r_o \quad (4)$$

Where $\tan(\alpha/2) = (r_1 - r_o)/\mathrm{h}$

If $A = \frac{150(1-\varepsilon)^2 \mu_g}{\varepsilon^3 (\phi_s d_p)^2}$

$B = 1.75\ (1-\varepsilon)\rho_g / \varepsilon^3 \phi_s d_p$

By considering ϕ_s =1 in this experiment eqn (4) becomes

$$-\Delta p = \frac{A u_{go}\, r_o}{r_1 h} + B u_{go}{}^2 r_o h [\frac{r_o^2 + r_o r_1 + r_1^2}{3 r_1^3}] \quad (5)$$

2.6.2 Condition of maximum pressure drop at point A

The buoyancy force exerted in the entire particles by fluid flowing upwards equals the effective gravitational force of all particles in the bed i.e.

$$\mathrm{F=G} \quad (6)$$

In the fixed bed regime the total pressure drop can be calculated by Ergun's eqn as follows

$$dp = (A u_g + B u_g{}^2) dh \quad (7)$$

In the larger radius r the buoyancy force exerted in the particles by the fluid is

$$dF = \pi r_o{}^2 dp$$

$$= \pi [A u_{go} r_o^2 + \frac{B u_{go}^2 ro^4}{r_o + \tan\left(\frac{\alpha}{2}\right)}] \quad (8)$$

Integrating equation (8) along the height of the conical bed gives

$$F = \pi r_o{}^2 h (A u_{go} + B u_{go}\, r_o / r_1) \quad (9)$$

At the same time the effective weight of particles in the layer is

$$dG = (1-\varepsilon)(\rho_s - \rho_g) g \pi r^2 dh \quad (10)$$

Integrating equation (10) along the height of the conical bed is gives

$$G = (1-\varepsilon)(\rho_s - \rho_g) g \pi r^2 h [(\frac{r_o^2 + r_o r_1 + r_1^2}{3 r_1^3})] \quad (11)$$

According to equation (5) the following equation is obtained for calculating the minimum fluidization velocity U_{mf}

$$\frac{Br_o u_{mf}}{r_1} + Au_{mf} - (1-\varepsilon)(\rho_s - \rho_g)g\left[\left(\frac{r_o^2 + r_o r_1 + r_1^2}{3r_1^3}\right)\right] = 0 \qquad (12)$$

The total pressure drop is also calculated by substituting u_{mf} in eqn (5)

2.6.3 Condition at point B

The fully fluidized bed occurs when the buoyancy force exerted on the particles in the top layer any fluid flowing upwards equals the effective gravitational force in the layer i.e.’

$$dF = dG \qquad (13)$$

By combining equation (8) and equation (10) the following equation is derived

$$A\left(\frac{r_o}{r_1}\right)^2 u_{ms} + B\left(\frac{r_o}{r_1}\right)^4 u_{ms} - (1-\varepsilon)(\rho_s - \rho_g)g = 0$$

CHAPTER 3

INTRODUCTION TO COMPUTATIONAL FLUID DYNAMICS (CFD)

3.1 Introduction to CFD

The flow of fluids of single phase has occupied the attention of scientists and engineers for many years. The equations for the motion and thermal properties of single phase fluids are well and closed form solutions for specific cases are well documented [26] .The state of the art for multiphase flows is considerably more primitive in that the correct formulation of the governing equations is still under debate .For this reason the study of multiphase flows represents a challenging and potentially fruitful area of endeavour. Hence there has been an increased research activity in the experimental and numerical study of multiphase flows. Multi-phase flows can be broadly classified into four groups; gas-liquid, gas-solid, liquid-solid and three phase flows. Gas-solid flows are usually considered to be a gas flow with suspended solid particles. This category includes pneumatic transport, bubbling/circulating fluidized beds and many others. In addition, there is also great deal of industrial interest in pure granular flows in equipment such as mixer ball mills and hoppers [27].

Various research groups to understand the gas-solid fluid dynamics are conducting theoretical experimental and numerical studies. Hydrodynamics modelling of gas-solid fluid dynamics are conducting theoretical experimental and numerical studies. Hydrodynamics modelling of gas-solid flows has been undertaken in one form or another for every forty years now. Fluidized beds are widely used in the chemical industries. They facilitate a large variety of operations ranging from coal gasification, coating metals objects with plastics drying of solid adsorption synthesis reactions, cracking of hydrocarbons and mixing etc. [28]. This variety of processes results in a large variety of fluidized bed reactors. In gas solid contact systems, gas bubble coalesces and grows as they rise and in a deep enough bed of small diameter they may eventually become large enough to spread across the vessel. The compelling advantage of the fluidized beds such as the smooth and liquid like flow particles allows a continuous automatically controlled operation with easy handling and rapid mixing solids etc. of small economy fluidized as contacting has been responsible for its successful use in industrial operations but such success depends on understandings and overcoming its disadvantages.

Currently here are two approaches for the numerical calculation of multiphase flows, the Euler-Lagrange approach and the Euler-Euler approach. In the Euler-Lagrange, the fluid phase is treated as a continuum by solving the time averaged Navier stokes equation, while the dispersed phase is solved by tracking a large number of particles (or bubbles, droplets) through the calculated flow fluid. The dispersed phase can exchange momentum, mass and energy with the fluid phase. A fundamental assumption made in this approach is that the dispersed second occupies a lower volume fraction.

In the Euler-Euler approaches, the different phase are treated mathematically as inter penetrating continua. Since the volume of phase cannot be occupied by another phase, the concept of the phase volume fraction is introduced. These volume fractions are assumed to be continuous fraction of time and space and their sum is equal to 1. For granular flows, such as flow in rising fluidized bed and other suspension systems, the Eulerian multiphase model is always the first choice and also for simulation in this research.

Assumptions

1) No mass transfer between the gas phase and solid phase.
2) External body force, lift force as well as virtual mass force is ignored.
3) Pressure gradient at fully fluidized condition is constant.
4) Density of each phase is constant.

3.2 What is CFD (Computational Fluid Dynamics)

CFD is predicting what will happen, quantitatively, when fluid flows [29], often with the complication of

- Simultaneous flow of heat
- Mass transfer
- Phase change (e.g. melting, freezing)
- Chemical reactions (e.g. Combustion)
- Mechanical movement(e.g. piston, fans)
- Stress & displacement

3.2.1 Advantage of CFD

1. Able to model physical fluid phenomenon that cannot easily be simulated or measured with a physical experiment. E.g. Weather system.

2. Able to model & investigate physical fluid systems more cost effectively and more rapidly than with experimental procedures. E.g. hypersonic aerospace vehicle.

3.2.2 Uses of CFD

1. Chemical engg. : to maintain yield from reactor and processing equipments.
2. Civil engg. : in creation of dams and aquaducts on quality and quantity of water Supply
3. Mechanical engg. : in design of pumps
4. Electrical engg. : in power plant design to attain maximum efficiency

3.2.3 Working Principle

1. CFD first builds a computational model [30] that represent a system or a device and that you want to study.
2. The geometry of interest is then divided or discreted into a number of computational cells called grids or mesh.

   Discretization is the method of approximating different equations by a system of algebraic equations for the variables at some set of discrete locations in space and time. The discrete locations are referred to as grids or mesh
3. The governing equation such as Navier stokes equation, continuity equations and energy equations etc. are discretized at each grid point using numerical analysis
   - Finite difference method
   - Finite element method
   - Finite volume method
4. The discretized algebra equations are then solved at each grid points by iterative means until a converged solution is obtained.
5. The values at other point are determined by interpolating the values between the grid values.

3.3 CFD Goals:

CFD can assist the design and optimization of new and existing processes and products.CFD can also be used for reducing energy costs, improving environmental performance and increasing productivity and profit margins. There are many potential applications of CFD in chemical processes [26, 28] where predicting the characteristics of fluid flow are important. A concerned effort by industry in partnership with government and academia is needed to make similar advances in CFD possible or the chemical and other low temperature process industries.

3.4 Current Industrial Applications:

CFD is routinely used today in a wide variety of disciplines and industries, including aerospace, automotive, power generation, chemical manufacturing, polymer processing, petroleum exploration, medical research, meteorology and astrophysics. The use of CFD in the process industry has led to reduction in the cost of product and process development and optimization activities reduce the need for physical experimentation. Shortened time to market, improved design reliability, increased conversions and yields and facilitated the resolution of environmental, health and right to operate issues. It follows that the economic benefit of using CFD has been substantial, although detailed economic analysis are rarely reported [27, 30].

CFD has an enormous potential impact on industry because the solution of equations of motion provides everything that is meaningful to know about the domain. For example, chemical engineers commonly make assumptions about the fluid mechanics in process units and piping that lead to great simplifications in the equations of motion. An agitated chemical reactor may be designed on the assumption that the material in the vessel is perfectly mixed, when, in reality, it is probably not perfectly mixed. Consequently, the fluid mechanics may limit the reaction rather than reaction kinetics and the design may be inadequate. CFD allows one to simulate the reactor without making any assumptions about the macroscopic flow pattern and thus to design the vessel properly the first time.

CHAPTER 4
MODELING AND SIMULATION OF CONICAL BED

4.1 Working Procedure

Computation fluid dynamics study of the bed is as follows using ANSYS 13.0 workbench:

ANSYS 13.0 [31] includes a great number of new and advanced features that make it easier, faster and cheaper for building complex structures. It has a geometry tool in the workbench to create every possible complex designs easily which was not there in GAMBIT.

Benefits of ANSYS are

- ✓ Greater veracity and allegiance: As the engineering requirements and design intricacy increases, simulation software must produce more accurate results that reflect changing operating conditions over time.
- ✓ Higher productivity: ANSYS 13.0 includes dozens of features that minimize the time and effort product development teams invest in simulation.
- ✓ More computational power.

The ANSYS workbench user interface makes the basic steps as that of GAMBIT:

- ✓ Creating Geometry.
- ✓ Building Mesh.
- ✓ Assigning zones types to a model.

4.2 Creating the Geometry in ANSYS DesignModeler

- ✓ Start ANSYS DesignModeler.

In the ANSYS Workbench [32] Project Schematic, double-click the Geometry cell in the fluid flow analysis system. This displays the ANSYS DesignModeler application. You can also right-click on the Geometry cell to display the context menu where you can select the New Geometry... option.

- ✓ Set the units in ANSYS DesignModeler.

When ANSYS DesignModeler first appears, you are prompted to select the desired system of length units to work from. For the purposes of this tutorial, where you will create the geometry in inches and perform the CFD analysis using SI units, select Inch as the desired length unit and click OK to close the prompt.

- ✓ Create the geometry.

1. Create a new plane by selecting YZPlane from the Tree Outline and click on New Plane from the Active Plane/Sketch toolbar, near the top of the ANSYS Workbench window. Clicking YZPlane first ensures that the new plane is based on the YZPlane.
2. Create a new sketch by selecting Plane4 from the Tree Outline and then click New Sketch from the Active Plane/Sketch toolbar, near the top of the ANSYS Workbench window. Clicking the plane first ensures that the new sketch is based on Plane4.
3. On the Sketching tab, open the Settings toolbox, select Grid, and enable the Show in 2D and the Snap options.
4. Set Major Grid Spacing to 1 in and Minor-Steps per Major to 2.
5. Give dimensions to the geometry from the dimension toolbar.
6. Specify the geometry as a fluid body.

   i. In the Tree Outline, open the 1 Part, 1 Body branch and select Solid branch.

   ii. In the Details View of the body, change the name of the Body from Solid to Fluid.

   iii. Change the Fluid/Solid property from Solid to Fluid.

4.3 Meshing the Geometry in the ANSYS Meshing Application

Meshing can be done in different ways:

- ✓ Triangular, quadrilateral, hexahedral, tetrahedral, prism etc.
- ✓ Structured and unstructured mesh

Here a mesh size of 0.5 mm is applied.

4.4 Specifying zones type

Zone type Specification defines the physical and operational characteristics of the Model at its boundaries and within specific region of its domain. There are two

Classes of zone type specification

- ➢ Boundary type
- ➢ Continuum type

Boundary type -:

In this type specifications, such as well, vent or inlet, define the characteristics of the model at its external or internal boundaries.

Continuum type -:

In this type specification, such as fluid or solid, define the characteristics of the model within specified regions of its domain. E.g. if you assign a fluid continuum type specification to a volume entity, the model is defined such that equations of momentum, continuity and species transport apply at mesh nodes or cells that exist within the volume. Conversely if you assign a solid continuum type specification to a volume entity, only the energy and species transport equations apply at the mesh nodes or cells that exist within the volume.

Fluid zone = group of cells for which all active equations are solved
Solid zone = group of cells for which only heat conduction problem solved.
No flow equations solved.

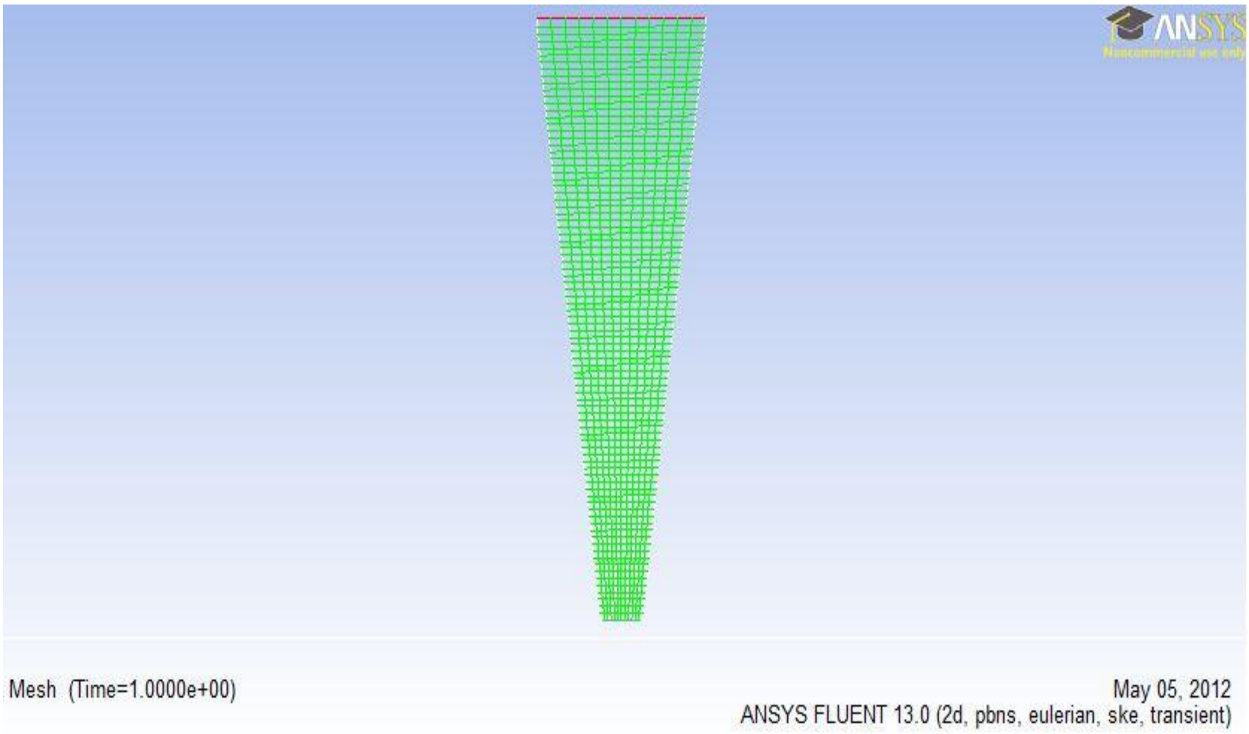


Fig.3 Grid generated using ANSYS 13.0

4.5 Setting up the CFD Simulation in ANSYS FLUENT

1) Launch Fluent and select solver 2D.
2) Read the case file.
1) Define Models (Solver properties)
   a) Select segregated, 2D, implicit, 1st order, unsteady, absolute, cell based, superficial velocity from solver.

b) Enable the Eulerian multiphase model with 2 phases.
c) Select laminar model.
d) Define the operating conditions, turn on the gravity and set the gravitational acceleration in the negative y direction, also give the reference pressure location.

2) Define Materials
    a) Select air as the primary phase and specify its density.
    b) Define a new fluid material (the glass beads) for the granular phase and specify its density.
3) Define Phases
    a) Specify air as the primary phase
    b) Specify glass beads or any solids as the secondary phase, select granular model and specify the diameter and volume fraction of solids, select the interphase interaction.
4) Boundary condition declaration
    a) Set conditions at velocity inlet with specifying the velocity magnitude at inlet for primary phase and for secondary phase keep the default value zero for velocity magnitude.
    b) Set the boundary conditions for the pressure outlet for mixture and both phases.
    c) Set the conditions for the wall for mixture and both phases.
5) Solution parameter setting
    a) Set the under relaxation for pressure, momentum and volume fraction of solids.
    b) Enable the plotting of residual during the calculation.
    c) Initialize the solution.
    d) Define an adaptation register for the lower half of the fluidized bed.
    e) Set a time step size and number of time steps for iteration, save the case and data files.

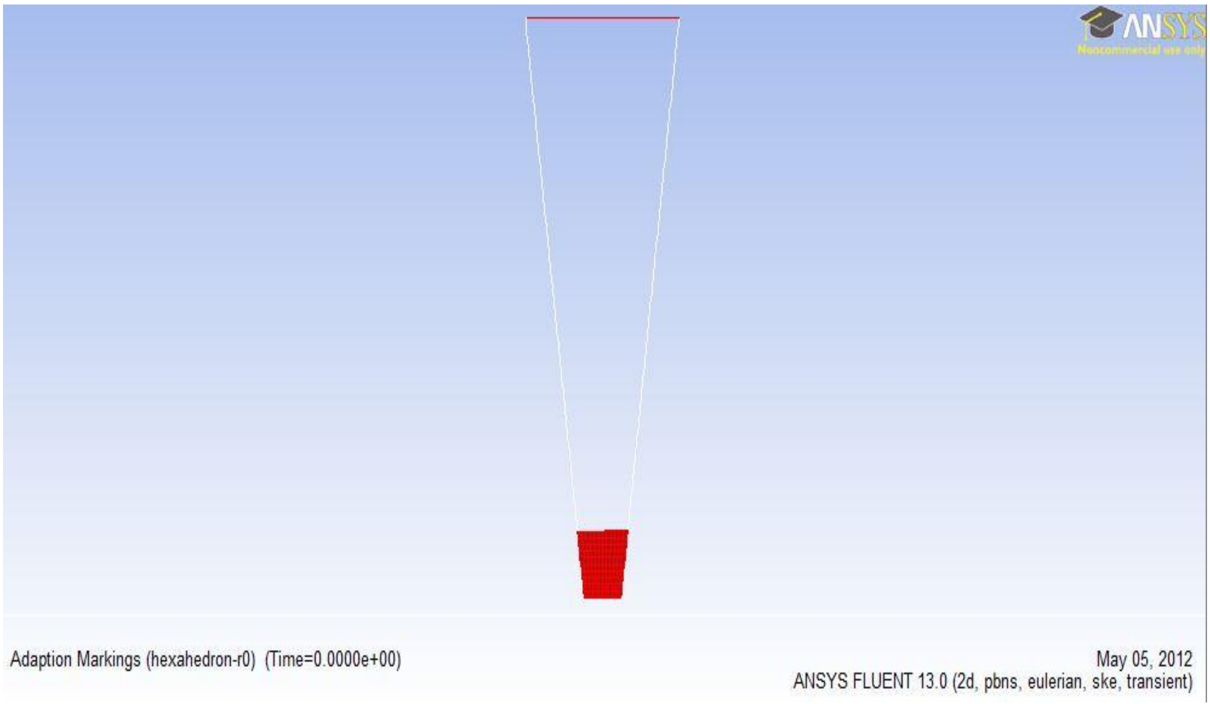


Fig.4 The adaption region

4.6 Post Processing

1) Select phase and volume fraction of the solids in the contours, we can see the contours of solids at each instant.
2) Similar step is followed for displaying contours of static pressure of mixture.

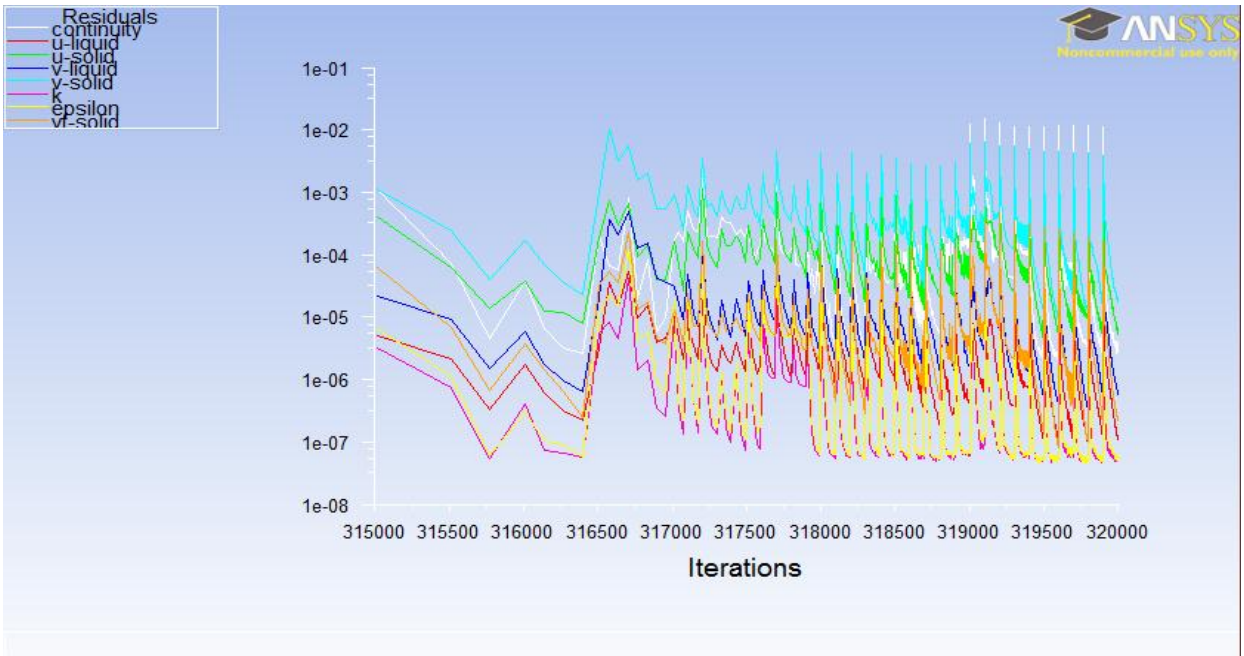


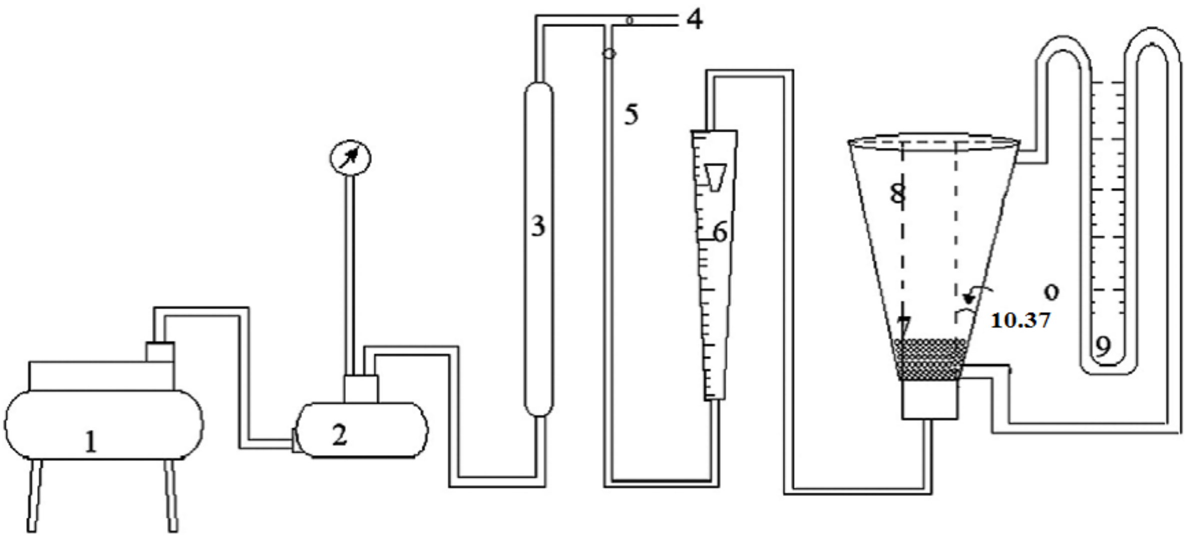
Fig.5 Solution calculation during simulation

CHAPTER 5

EXPERIMENTAL SET UP AND RESULT

5.1 Experimental Set-up

The schematic diagram of experimental set-up is shown below.



Experimental set-up. 1. Compressor. 2. Receiver. 3. Silica gel tower. 4. Bypass valve. 5. Line valve. 6. Rotameter. 7. Bed materials. 8. Fluidizer. 9. Pressure tapping to manometer.

Fig.6 Schematic diagram of experimental set-up for conical bed fluidization

5.2 Experimental Procedure

1) The experiment has been conducted in a Perspex glass column.
2) An air compressor was used to inject the gas (air) into the column from bottom. A claiming section is provided below the distributor plate for uniform distribution of the air.
3) Rotameter was used to measure the flow rate of the air and manometer is provided to the bed to monitor the pressure drop.
4) A weighed amount of material was charged to the fluidizer and the slant static bed height is recorded.

5) Air flow rate was gradually increased and the corresponding manometer fluid level in both the limbs is noted.
6) After the point of incipient fluidization the expanded bed heights (slant) were also noted down.
7) As the bed fluctuated between two limits typically of gas solid fluidization, the upper and lower surfaces of the fluctuating bed were recorded for each fluid velocity higher than the minimum fluidizing ones.
8) The above procedure had been repeated for different amount of samples of varying particle sizes and for different type of materials.

Specifications:

1) Cone specification:
   Inlet diameter (D_0) = 5 cm
   Outlet diameter (D_1) = 17.4 cm
   Height of column = 46.8 cm
   Angle of cone $=10.37^0$
   Area of inlet (A_0) $= (\pi/4)^* (D_0)^2$
   $= 0.001962\ m^2$
2) Density of fluid (air) $=1.18\ Kg/m^3$
3) Viscosity of Fluid (air) $=0.0000185\ Kg/m^2s$
4) Density of Manometer fluid (CCl_4) $=1554\ Kg/m^3$

5.3.1 Experimental Results

Material Type- Glass bead

Particle size (BSS -6 + 7) - 0.00258m , Density of solids - 2300 Kg/m^3

Weight - 150 grams, Porosity - 0.4, Height of Bed- 5.6 cm

Table.5.3.1

SI No	Rotameter Reading (m^3/hr)	Velocity (m/s)	h_1 (cm)	h_2 (cm)	Δh (cm)	Bed height (cm)	ΔP_1 (N/m^2)
1	0	0	65	65	0	5.6	0
2	2	0.2883	65.7	64.3	1.4	5.6	213.426
3	4	0.5769	66.1	63.8	2.3	5.6	350.629
4	6	0.8653	66.8	63.5	3.3	5.6	503.076
5	8	1.1538	67.7	62.5	5.2	5.6	792.726
6	10	1.4422	68.6	61.7	6.9	6.2	1051.887
7	12	1.7307	68.6	61.7	6.9	7.4	1051.887
8	14	2.0191	68.6	61.7	6.9	8.2	1051.887
9	16	2.3076	68.6	61.7	6.9	9.5	1051.887
10	18	2.5960	68.6	61.7	6.9	11	1051.887

Material Type- Glass beads

Particle size (BSS -6 + 7) - 0.00258m, Density of solids - 2300 Kg/m3

Weight - 200 grams, Porosity - 0.42, Height of bed - 7.4 cm

Table.5.3.2

SI No	Rotameter Reading (m^3/hr)	Velocity (m/s)	h_1 (cm)	h_2 (cm)	Δh (cm)	Bed height (cm)	ΔP_2 (N/m^2)
1	0	0	65	65	0	7.4	0
2	2	0.2884	65.6	64.4	1.2	7.4	182.936
3	4	0.5769	66	64.1	1.9	7.4	289.650
4	6	0.8653	66.7	64	2.7	7.4	411.607
5	8	1.1538	67.8	62.9	4.9	7.4	746.992
6	10	1.4422	68.5	62.7	5.8	7.4	884.194
7	12	1.7307	69.1	62.6	6.5	7.4	990.908
8	14	2.0191	69.7	61.5	8.2	9.3	1250.068
9	16	2.3076	69.7	61.5	8.2	10.4	1250.068
10	18	2.5960	69.7	61.5	8.2	11.9	1250.068
11	20	2.8315	69.7	61.5	8.2	13	1250.068

Material type-Glass beads

Particle size (BSS -7 + 8) = 0.00218 m, density of solids = 2300 kg/m3 Weight = 150 gms,Porosity = 0.385, Height of bed = 5.9 cm

Table.5.3.3

SI No	Rotameter Reading (m^3/hr)	Velocity (m/s)	h_1 (cm)	h_2 (cm)	Δh (cm)	Bed height (cm)	ΔP_1 (N/m^2)
1	0	0	65	65	0	5.9	0
2	2	0.2884	65.5	64.2	1.3	5.9	198.181
3	4	0.5769	66.2	63.8	2.4	5.9	365.873
4	6	0.8653	66.9	63.1	3.8	5.9	579.300
5	8	1.1538	67.8	61.3	6.5	6.4	990.908
6	10	1.4422	67.8	61.3	6.5	7.8	990.908
7	12	1.7307	67.8	61.3	6.5	8.5	990.908
8	14	2.0191	67.8	61.3	6.5	9.7	990.908
9	16	2.3076	67.8	61.3	6.5	10.3	990.908
10	18	2.5960	67.8	61.3	6.5	11.2	990.908

Material type-Glass beads
Particle size (BSS -7+8) = 0.00218 m, density of solids = 2300 kg/m3

Weight = 250 gms,Porosity = 0.441,Height of bed = 10 cm

Table.5.3.4

SI No	Rotameter Reading (m^3/hr)	Velocity (m/s)	h_1 (cm)	h_2 (cm)	Δh (cm)	Bed height (cm)	ΔP_2 (N/m^2)
1	0	0	65	65	0	10	0
2	2	0.2884	66.2	63.8	1.6	10	243.915
3	4	0.5769	66.7	63.3	2.9	10	442.097
4	6	0.8653	67.3	62.3	4.4	10	670.768
5	8	1.1538	68.1	60.3	7	10	1067.131
6	10	1.4422	68.5	59.8	8.3	10	1265.313
7	12	1.7307	68.9	59.1	9.4	10	1433.005
8	14	2.0191	70.4	59	9.9	10	1509.229
9	16	2.3076	70.4	61.3	9.1	12.5	1387.271
10	18	2.5960	70.4	61.3	9.1	13.7	1387.271
11	20	2.8315	70.4	61.3	9.1	15	1387.271
12	22	3.1147	70.4	61.3	9.1	16.4	1387.271

Material Type – Coal

Particle size (BSS -12 +14) – 0.0013, Density of solids – 1545 kg/m^3, weight – 75 grams
Porosity – 0.312, Height of bed – 7.3 cm

Table.5.3.5

SI No	Rotameter Reading (m^3/hr)	Velocity (m/s)	h_1 (cm)	h_2 (cm)	Δh (cm)	Bed height (cm)	ΔP_2 (N/m^2)
1	0	0	65	65	0	7.3	0
2	2	0.2884	65.5	64.4	1.1	7.3	167.692
3	4	0.5769	66.1	63.9	1.9	7.3	289.650
4	6	0.8653	66.3	63.8	2.3	7.3	350.629
5	8	1.1538	66.4	63.7	2.5	7.3	381.118
6	9	1.2742	66.4	63.7	2.7	12.2	411.607
7	10	1.4422	66.4	63.7	2.7	13.5	411.607
8	11	1.5573	66.4	63.7	2.7	14.1	411.607

Material Type – Coal

Particle size (BSS-12 + 14) – 0.0013m , density of solids – 1545 kg/m3,Weight – 100 gms,
Porosity – 0.257, Height of bed – 10.3

Table.5.3.6

SI No	Rotameter Reading (m^3/hr)	Velocity (m/s)	h_1 (cm)	h_2 (cm)	Δh (cm)	Bed height (cm)	ΔP_2 (N/m^2)
1	0	0	65	65	0	10.3	0
2	2	0.2884	65.6	63.8	1.4	10.3	213.426
3	4	0.5769	66.3	63.2	2.1	10.3	320.139
4	6	0.8653	66.5	63	2.9	10.3	442.097
5	8	1.1538	66.5	63	3.3	10.3	503.076
6	9	1.2742	66.5	63	3.5	10.3	533.565
7	10	1.4422	66.5	63	3.7	12.4	564.055
8	11	1.5573	66.5	63	3.7	14	564.055

Material Type – Iron

Particle size (BSS-12 + 14) – 0.0013, Density of solids – 2500 kg/m^3, weight – 250 grams

Porosity – 0.388, Height of bed – 7.1 cm

Table.5.3.7

SI No	Rotameter Reading (m^3/hr	Velocity (m/s)	h_1 (cm)	h_2 (cm)	Δh (cm)	Bed height (cm)	ΔP_1 (N/m^2
1	0	0	72.3	72.3	0	7.1	0
2	2	0.2884	72.9	71.1	1.8	7.1	274.405
3	4	0.5769	73.5	70.2	3.3	7.1	503.076
4	6	0.8653	73.8	68.6	5.2	7.1	792.726
5	8	1.1538	74.6	66.9	7.7	7.1	1173.844
6	10	1.4422	75.3	66.5	8.8	7.1	1341.537
7	12	1.7307	75.1	66.4	8.7	7.1	1326.292
8	14	2.0191	75	66.9	8.1	7.1	1234.823
9	16	2.3076	75.1	67.2	7.9	11.9	1204.334
10	18	2.5960	75.1	67.2	7.9	13.1	1204.334
11	20	2.8315	75.1	67.2	7.9	14.4	1204.334

Material Type – Iron

Particle size (BSS-12 + 14) – 0.0013, Density of solids – 2500 kg/m^3, Weight = 300 gms, Porosity = 0.338, Height of bed = 8.2 cm

Table.5.3.8

SI No	Rotameter Reading (m^3/hr)	Velocity (m/s)	h_1 (cm)	h_2 (cm)	Δh (cm)	Bed height (cm)	ΔP_2 (N/m^2)
1	0	0	72.3	72.3	0	8.2	0
2	2	0.2884	73.2	71.2	2	8.2	304.894
3	4	0.5769	73.6	70.3	3.5	8.2	533.565
4	6	0.8653	74.4	69.1	5.3	8.2	807.971
5	8	1.1538	75.9	67.7	8.2	8.2	1250.068
6	10	1.4422	76.7	67.4	9.3	8.2	1417.76
7	12	1.7307	77.3	66.8	10.5	8.2	1600.697
8	14	2.0191	77.8	68	9.8	8.2	1493.984
9	16	2.3076	77.9	68.3	9.6	8.2	1463.495
10	18	2.5960	78	68.7	9.3	12.9	1417.76
11	20	2.8315	78	68.7	9.3	14.5	1417.76
12	22	3.1147	78	68.7	9.3	16	1417.76

5.3.2 Sample Calculation

Material type = Coal particles

Particle size = 0.00258 m

Bed height = 5.6cm

Weight of solid = 150gms

At flow rate (rota meter reading) Q = 6 m^3/hr

Area of inlet (A_0) = 0.001962 m^2

Velocity = Q/A_0 = 6/0.001962

= 0.8653 m/s

Manometer fluid level h_1 = 62.8 cm

h_2 = 63.5 cm

Difference in level Δh = 3.3 cm

Acceleration due to gravity (g) =9.81 m/s^2

Density of manometer fluid (CCl_4) 'ρ' =1554 Kg/m^3

So, Pressure drop $\Delta P = \rho * g * \Delta h$ =1554*9.81*0.033

= 503.076N/m^2

CHAPTER 6

RESULTS AND DISCUSSIONS

6.1 Experimental analysis

The data obtained from the three samples such as glass beads,coal particles and iron were plotted and the following curves are obtained:

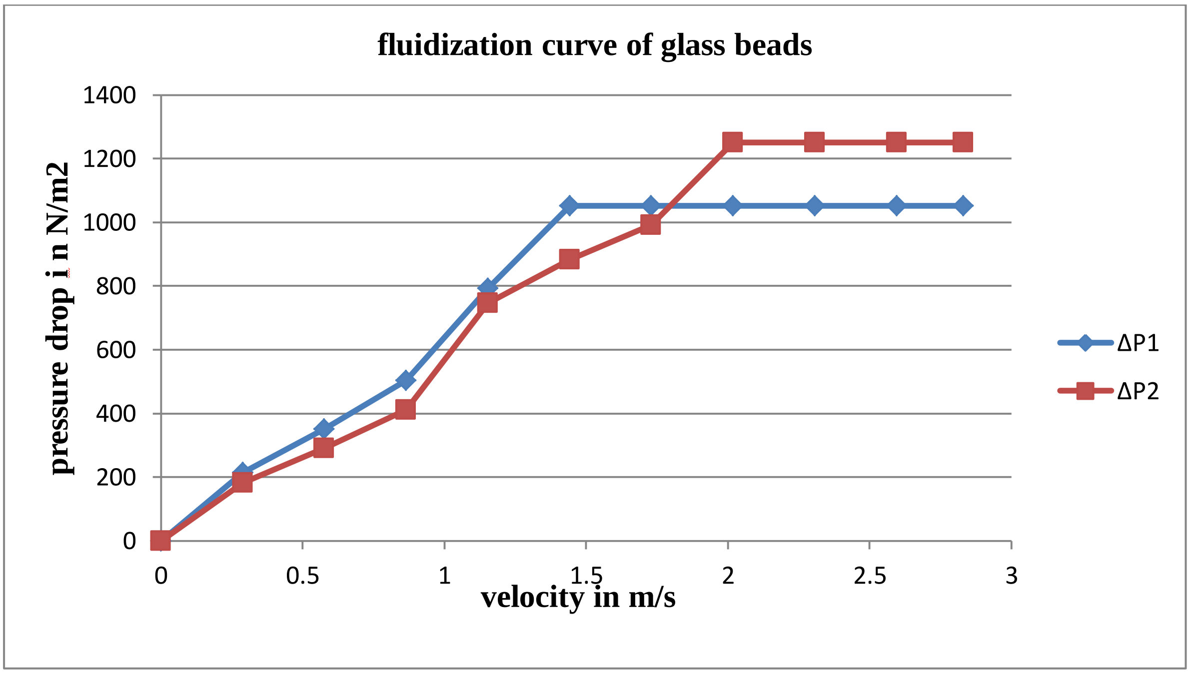


Fig.7 Pressure drop vs superficial gas velocity for glass beads of particle size 0.00258m

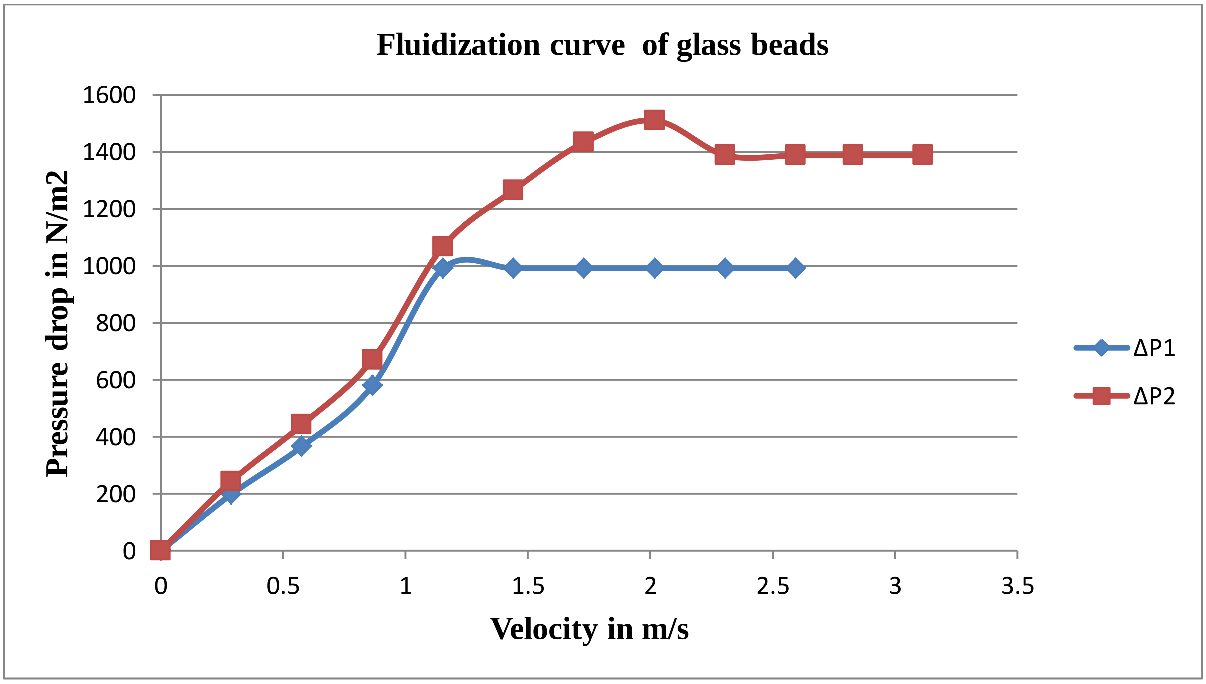


Fig.8 Pressure drop vs superficial gas velocity for glass beads of size 0.00218m

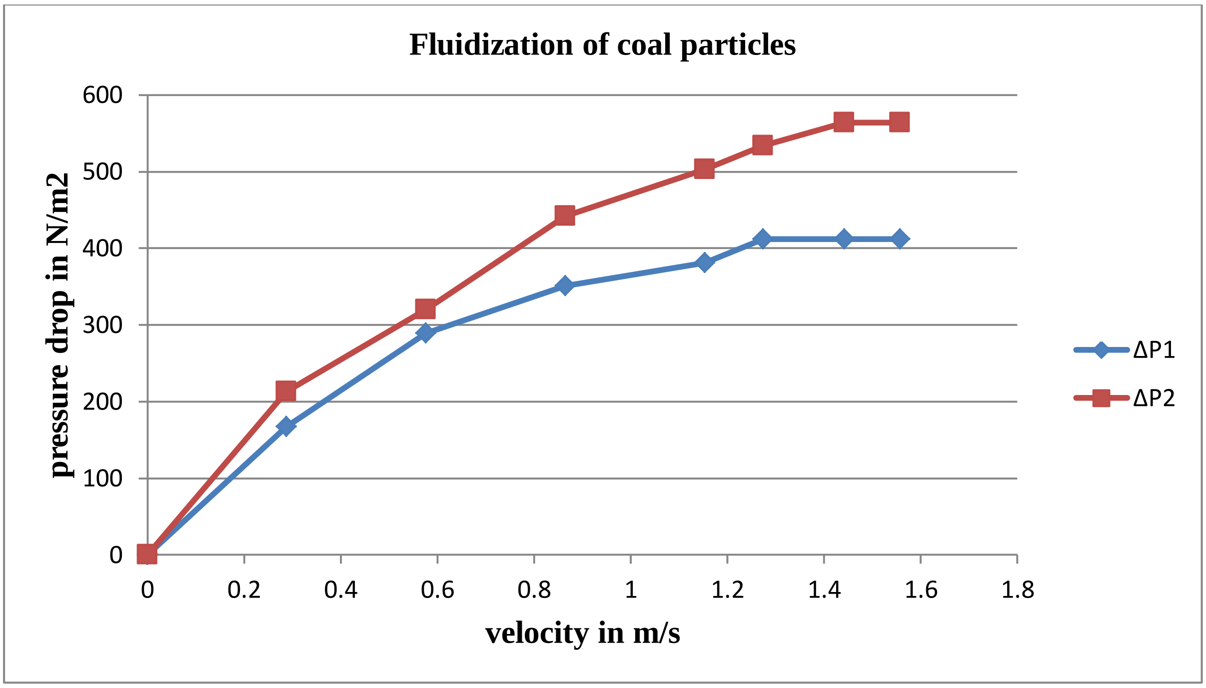


Fig.9 Pressure drop vs Superficial gas velocity for coal particles of size 0.0013m

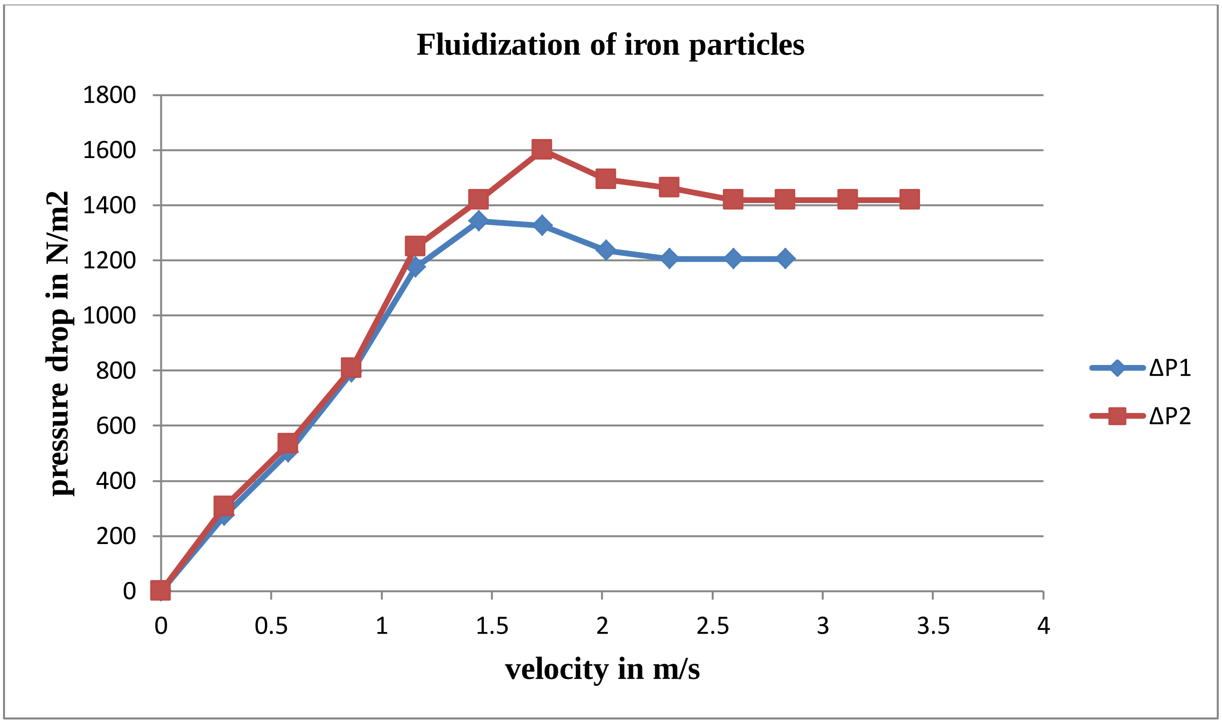


Fig.10 Pressure drop vs Superficial gas velocity for iron particles of size 0.0013m

6.2 Modeling and simulation results

Variation of bed profile with different flow rates,bed height and paricles size at 5 second time obtained from CFD are shown in fig :

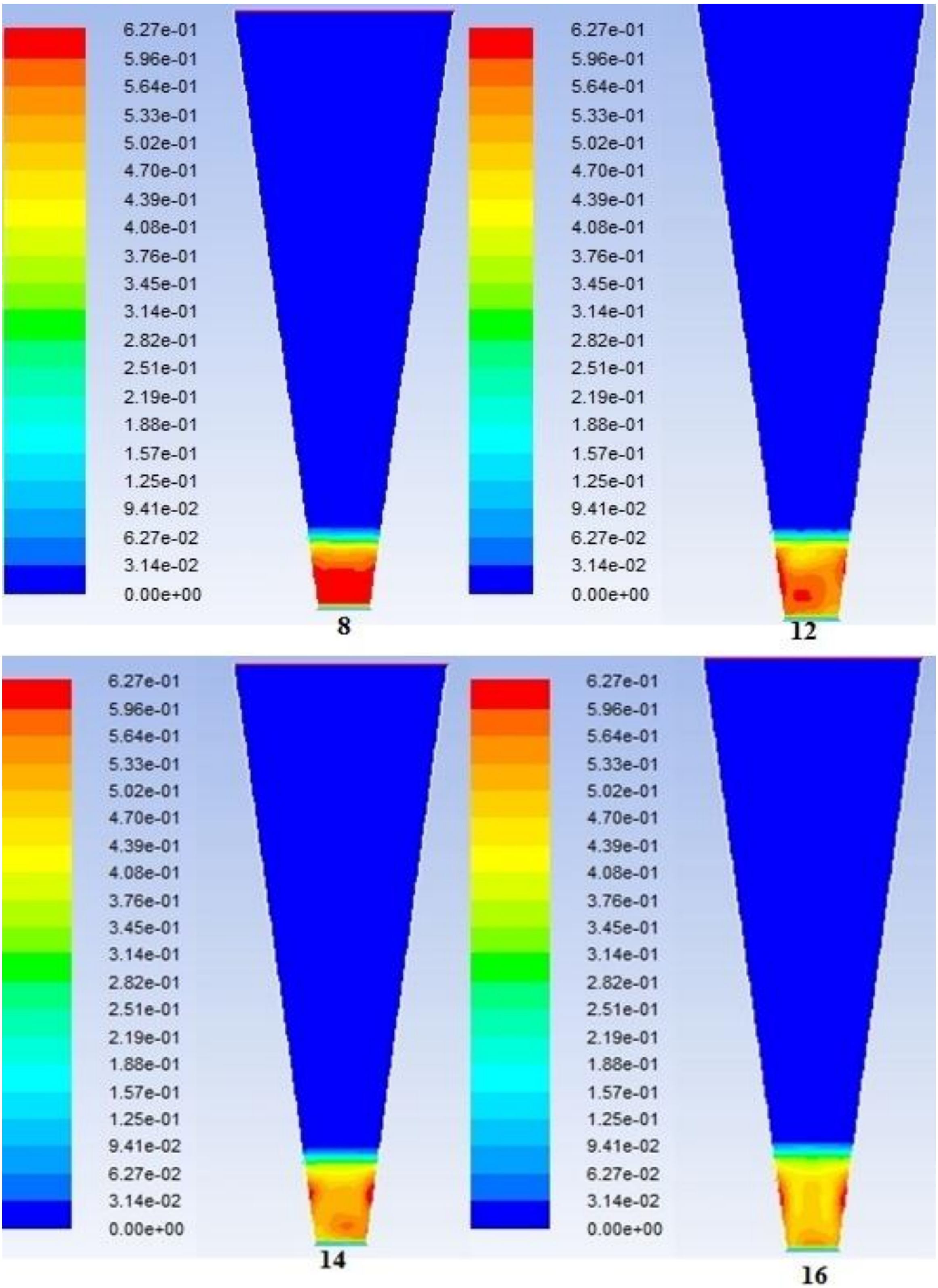


Fig.11 Contours of volume fraction for glass beads at bed height = 5.6 cm at different flow rates after 5 sec

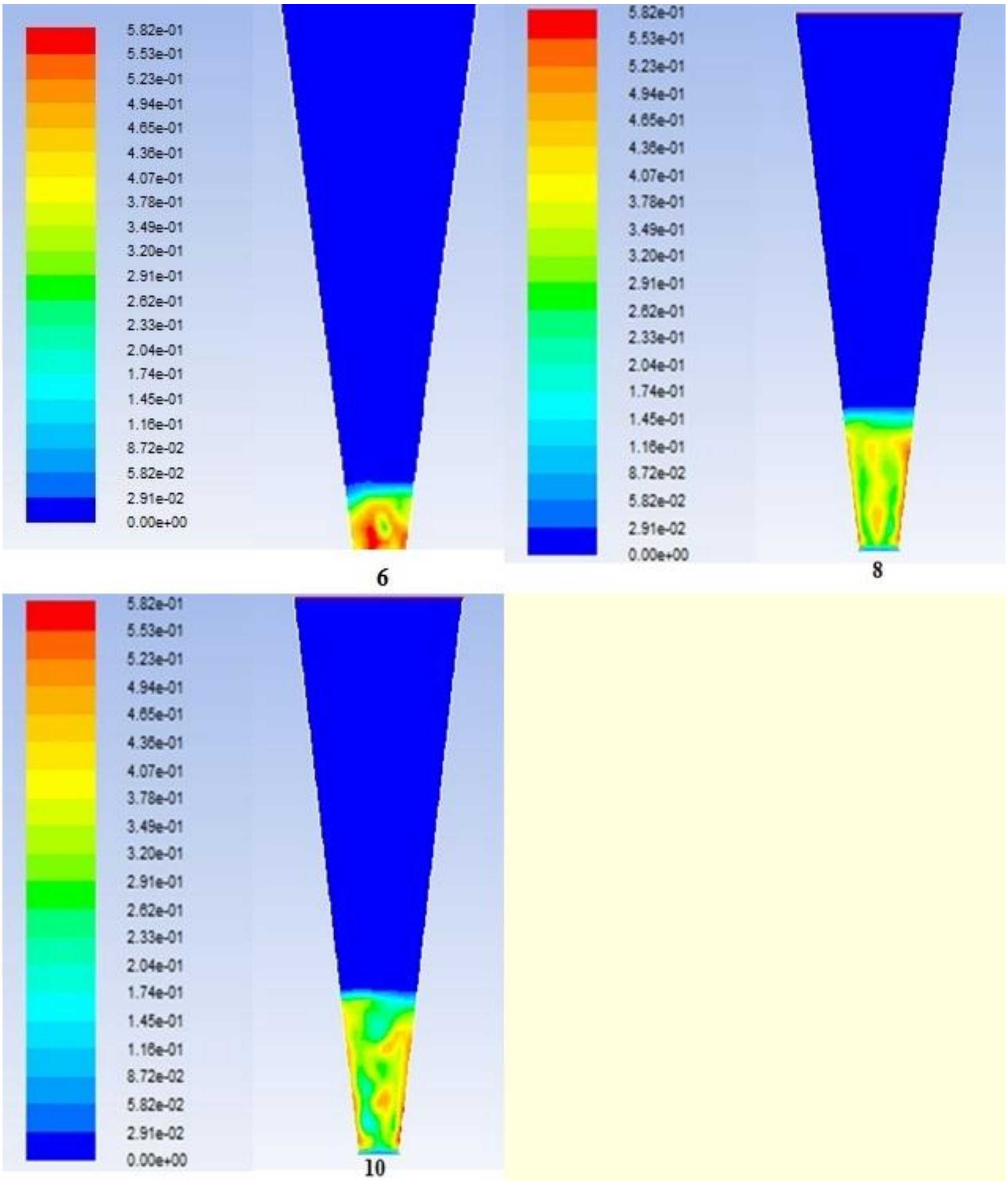


Fig.12 Contours of volume fraction for Coal particles at bed height = 7.3 cm at different flow rates after 15 sec

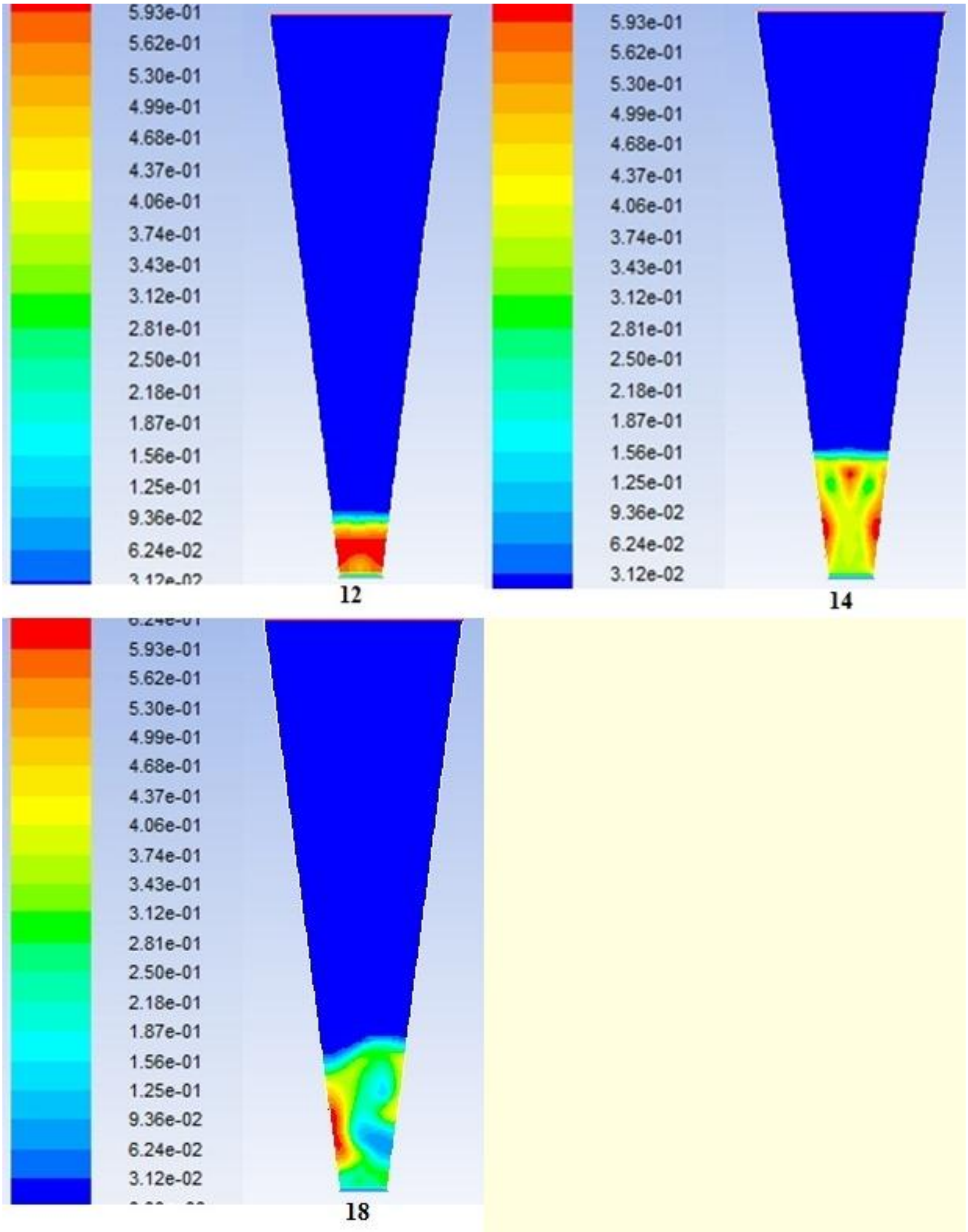


Fig.13 Contours of volume fraction for Iron particles at bed height=7.1 cm at different flow rates after 10 sec

6.3 Comparison between experimental and simulation results

From table 1 : Material type - Glass beads
Particle size (BSS -6 + 7) - 0.00258m
Density of solids - 2300 kg /m^3
Weight - 150 grams
Porosity(ϵ) - 0.4
Height of bed - 5.6 cm

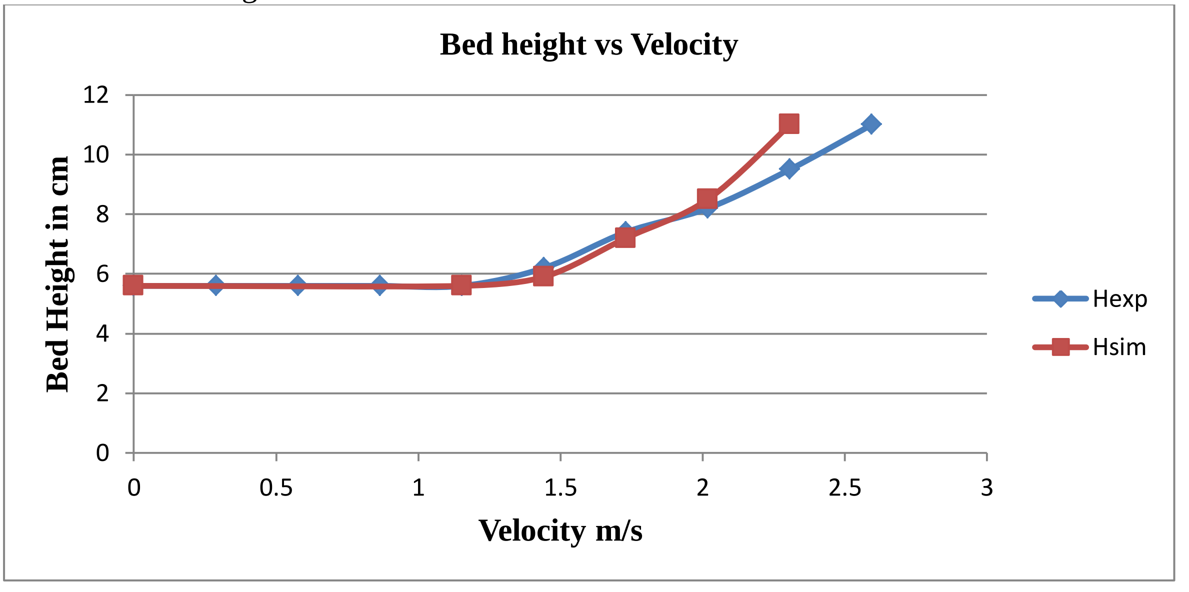


Fig.14 Variation of bed height with Superficial Velocity

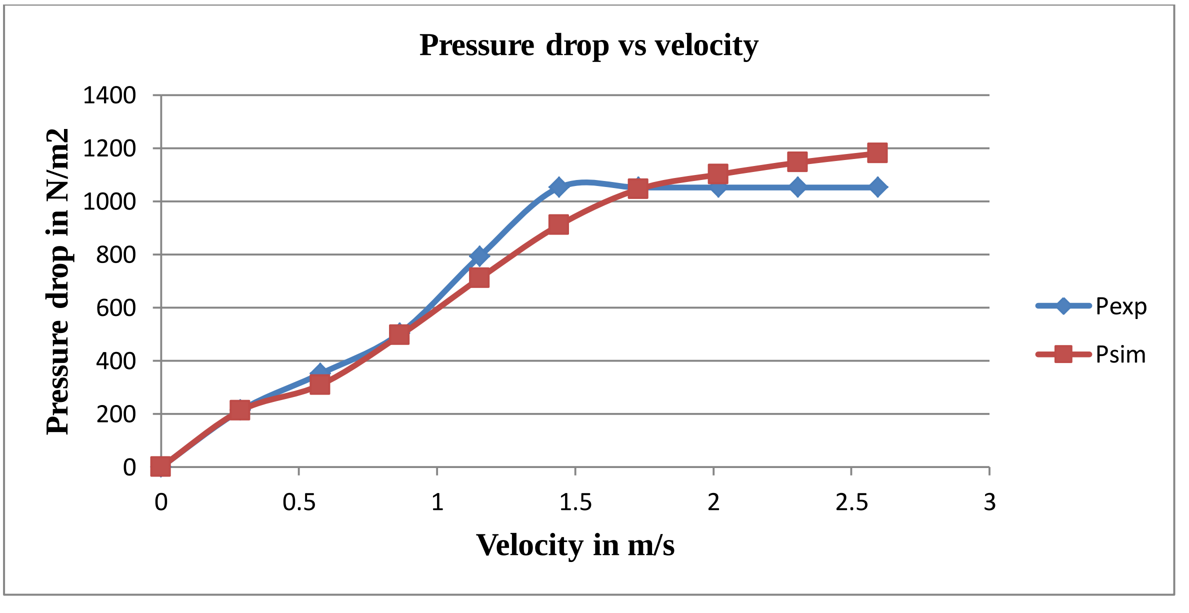


Fig.15 Variation of pressure drop vs Superficial velocity

All comparisons shown above clrearly depict that experimental and CFD simulated results are in good agreement with each other

6.4 Discussion

The hydrodynamic characteristics of a conical bed with different particle size and different bed have been studied experimentally for glass beads and coal particles. The result shows that three flow regimes takes place: fixed bed, partially fluidized bed, fully fluidized bed depending on superficial gas velocity.

The bed void age remains unchanged in the fixed bed regime. With same particle size and different bed heights, the total pressure drops of the bed increases. The minimum fluidization velocity also increases with increase in bed height. Similarly the maximum pressure drop is higher for the bed having more stagnant height.

With increase in static bed height, more gas will leak into the annulus region or spread out laterally. As a result more fluid is required to fluidize the top central region of the bed, leading to an increase in the minimum fluidization velocity. With increase in particle diameter, the minimum fluidization velocity and total pressure drop increases.

CHAPTER 7

CONCLUSIONS

A comprehensive hydrodynamics study has been successfully carried out on conical bed. Empirical correlations were developed for the minimum fluidization velocity and total pressure drop. Experimental analysis is done and the pressure drop versus velocity curve is in accordance with the theoretical curve. The CFD model is evaluated with the theoretical curve. The CFD is evaluated with the experimental data. On comparison between simulated results and experimental data, sometime simulated result underestimated experimental data. This suggests that there exists some kind of systematic error either in experiment or in CFD modelling.

Some factors like grid partition, time step size, convergence criterion directly affect the result in the experimental as well as in CFD simulation, gas velocity is the main parameter that affects both, but the impact is more in case of simulation results on gas mixing behaviour. It is been observed that in experiment as well as in CFD, with increase in static bed height, more gas will leak into the annulus region or spread out laterally. As a result more fluid is required to fluidize the top central region of the bed, leading to an increase in the minimum fluidization velocity. With increase in particle diameter, the minimum velocity and total pressure drop increases.

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